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INVENTOR(S)			
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Lawrence	ROSENBERG	6507 Fern Road, C6te St-Luc, Qu6bec, CANADA H4V 1E4	
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TITLE OF THE INVENTION (280 characters max)			
REVERSAL OF DIABETES IN NOD MICE WITH A COMBINATION OF INGP PEPTIDE AND SIROLIMUS/TACROLIMUS			
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Respectfully submitted,

SIGNATURE

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October 24, 2002

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37,037

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**REVERSAL OF DIABETES IN NOD MICE WITH A COMBINATION OF
INGAP PEPTIDE AND SIROLIMUS/TACROLIMUS**

BACKGROUND OF THE INVENTION

5 (a) Field of the Invention

This invention relates to a method to stimulate reversal of a diabetic state in a patient; a method to prevent autoimmune destruction of new insulin-producing cells (pancreatic beta-cells) in a patient; a method to promote survival of the newly regenerated insulin-producing cells (pancreatic beta-cells); and an *in vivo* method for the induction of islet cell neogenesis and new islet formation and the prevention of autoimmune destruction of said new cells.

(b) Description of Prior Art

Diabetes

15 Diabetes mellitus has been classified as type I, or insulin-dependent diabetes mellitus (IDDM) and type II, or non-insulin-dependent diabetes mellitus (NIDDM). NIDDM patients have been subdivided further into (a) nonobese (possibly IDDM in evolution), (b) obese, and (c) maturity onset (in young patients). Among the population with diabetes mellitus, about 20% suffer from IDDM. Diabetes develops either when a diminished insulin output occurs or when a diminished sensitivity to insulin cannot be compensated for by an augmented capacity for insulin secretion. In patients with IDDM, a decrease in insulin secretion is the principal factor in the pathogenesis, whereas in patients with NIDDM, a decrease in insulin sensitivity is the primary factor. The mainstay of diabetes treatment, especially for type I disease, has been the administration of exogenous insulin.

Rationale for more physiologic therapies

30 Tight glucose control appears to be the key to the prevention of the secondary complications of diabetes. The results of the Diabetes Complications and Control Trial (DCCT), a multicenter randomized trial of 1441 patients with insulin dependent diabetes, indicated that the onset and progression of diabetic retinopathy, nephropathy, and neuropathy could be

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- slowed by intensive insulin therapy (The Diabetes Control and Complication Trial Research Group, *N. Engl. J. Med.*, 1993; 29:977-986). Strict glucose control, however, was associated with a three-fold increase in incidence of severe hypoglycemia, including episodes of seizure and coma. As well, although glycosylated hemoglobin levels decreased in the treatment group, only 5% maintained an average level below 6.05% despite the enormous amount of effort and resources allocated to the support of patients on the intensive regime (The Diabetes Control and Complication Trial Research Group, *N. Engl. J. Med.*, 1993; 29:977-986).
- 5 The results of the DCCT clearly indicated that intensive control of glucose can significantly reduce (but not completely protect against) the long-term microvascular complications of diabetes mellitus.
- 10

Other therapeutic options

- 15 The delivery of insulin in a physiologic manner has been an elusive goal since insulin was first purified by Banting, Best, McLeod and Collip. Even in a patient with tight glucose control, however, exogenous insulin has not been able to achieve the glucose metabolism of an endogenous insulin source that responds to moment-to-moment changes in glucose concentration and therefore protects against the development of microvascular complications over the long term.
- 20

- A major goal of diabetes research, therefore, has been the development of new forms of treatment that endeavor to reproduce more closely the normal physiologic state. One such approach, a closed-loop insulin pump coupled to a glucose sensor, mimicking β -cell function in which the secretion of insulin is closely regulated, has not yet been successful. Only total endocrine replacement therapy in the form of a transplant has proven effective in the treatment of diabetes mellitus. Although transplants of insulin-producing tissue are a logical advance over subcutaneous insulin injections, it is still far from clear whether the risks of the intervention and of the associated long-term immunosuppressive treatment are lower those in diabetic patients under conventional treatment.
- 25
- 30

- Despite the early evidence of the potential benefits of vascularized pancreas transplantation, it remains a complex surgical
- 35

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intervention, requiring the long-term administration of chronic immunosuppression with its attendant side effects. Moreover, almost 50% of successfully transplanted patients exhibit impaired tolerance curves (Wright FH et al., *Arch. Surg.*, 1989;124:796-799; Landgraft R et al., *Diabetologia* 1991; 34 (suppl 1):S61; Morel P et al., *Transplantation* 1991; 51:990-1000), raising questions about their protection against the long-term complications of chronic hyperglycemia.

The major complications of whole pancreas transplantation, as well as the requirement for long term immunosuppression, has limited its wider application and provided impetus for the development of islet transplantation. Theoretically, the transplantation of islets alone, while enabling tight glycemic control, has several potential advantages over whole pancreas transplantation. These include the following: (i) minimal surgical morbidity, with the infusion of islets directly into the liver via the portal vein; (ii) the possibility of simple re-transplantation for graft failures; (iii) the exclusion of complications associated with the exocrine pancreas; (iv) the possibility that islets are less immunogenic, eliminating the need for immunosuppression and enabling early transplantation into non-uremic diabetics; (v) the possibility of modifying islets in vitro prior to transplantation to reduce their immunogenicity; (vi) the ability to encapsulate islets in artificial membranes to isolate them from the host immune system; and (vii) the related possibility of using xenotransplantation of islets immunoisolated as part of a biohybrid system. Moreover, they permit the banking of the endocrine cryopreserved tissue and a careful and standardized quality control program before the implantation.

The problem of islet transplantation

Adequate numbers of isogenetic islets transplanted into a reliable implantation site can only reverse the metabolic abnormalities in diabetic recipients in the short term. In those that were normoglycemic post-transplant, hyperglycemia recurred within 3-12 mo. (Orloff M, et. al., *Transplantation* 1988; 45:307). The return of the diabetic state that occurs with time has been attributed either to the ectopic location of the islets, to a disruption of the enteroinsular axis, or to the transplantation of an

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inadequate islet cell mass (Bretzel RG, et al. In: Bretzel RG, (ed) Diabetes mellitus (Berlin: Springer, 1990) p.229).

5 Studies of the long term natural history of the islet transplant, that
examine parameters other than graft function, are few in number. Only one
report was found in which an attempt was specifically made to study graft
morphology (Alejandro R, et. al., *J Clin Invest* 1986; 78: 1339). In that
study, purified islets were transplanted into the canine liver via the portal
vein. During prolonged follow-up, delayed failures of graft function
10 occurred. Unfortunately, the graft was only examined at the end of the
study, and not over time as function declined. Delayed graft failures have
also been confirmed by other investigators for dogs (Warnock GL et. al.,
Can. J. Surg., 1988; 31: 421 and primates (Sutton R, et. al., *Transplant
Proc.*, 1987; 19: 3525). Most failures are presumed to be the result of
rejection despite appropriate immunosuppression.

15 Because of these failures, there is currently much enthusiasm for
the immunoisolation of islets, which could eliminate the need for
immunosuppression. The reasons are compelling. Immunosuppression is
harmful to the recipient, and may impair islet function and possibly cell
survival (Metrakos P, et al., *J. Surg. Res.*, 1993; 54: 375). Unfortunately,
20 micro-encapsulated islets injected into the peritoneal cavity of the dog fail
within 6 months (Soon-Shiong P, et. al., *Transplantation* 1992; 54: 769),
and islets placed into a vascularized biohybrid pancreas also fail, but at
about one year. In each instance, however, histological evaluation of the
graft has indicated a substantial loss of islet mass in these devices (Lanza
25 RP, et. al., *Diabetes* 1992; 41: 1503). No reasons have been advanced for
these changes. Therefore maintenance of an effective islet cell mass post-
transplantation remains a significant problem.

In addition to this unresolved issue, is the ongoing problem of the
lack of source tissue for transplantation. The number of human donors is
30 insufficient to keep up with the potential number of recipients. Moreover,
given the current state of the art of islet isolation, the number of islets that
can be isolated from one pancreas is far from the number required to
effectively reverse hyperglycemia in a human recipient.

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In response, three competing technologies have been proposed and are under development. First, islet cryopreservation and islet banking. The techniques involved, though, are expensive and cumbersome, and do not easily lend themselves to widespread adoption. In addition, islet cell mass is also lost during the freeze-thaw cycle. Therefore this is a poor long-term solution to the problem of insufficient islet cell mass. Second, is the development of islet xenotransplantation. This idea has been coupled to islet encapsulation technology to produce a biohybrid implant that does not, at least in theory, require immunosuppression. There remain many problems to solve with this approach, not least of which, is that the problem of the maintenance of islet cell mass in the post-transplant still remains. Third, is the resort to human fetal tissue, which should have a great capacity to be expanded *ex vivo* and then transplanted. However, in addition to the problems of limited tissue availability, immunogenicity, there are complex ethical issues surrounding the use of such a tissue source that will not soon be resolved. However, there is an alternative that offers similar possibilities for near unlimited cell mass expansion.

An entirely novel approach, proposed by Rosenberg in 1995 (Rosenberg L et al., *Cell Transplantation*, 1995; 4:371-384), was the development of technology to control and modulate islet cell neogenesis and new islet formation, both *in vitro* and *in vivo*. The concept assumed that (a) the induction of islet cell differentiation was in fact controllable; (b) implied the persistence of a stem cell-like cell in the adult pancreas; and (c) that the signal(s) that would drive the whole process could be identified and manipulated.

In a series of *in vivo* studies, Rosenberg and co-workers established that these concepts were valid in principle, in the *in vivo* setting (Rosenberg L et al., *Diabetes*, 1988; 37:334-341; Rosenberg L et al., *Diabetologia*, 1996; 39:256-262), and that diabetes could be reversed.

The well known teachings of *in vitro* islet cell expansion from a non-fetal tissue source comes from Peck and co-workers (Corneliu JG et al., *Horm. Metab. Res.*, 1997; 29:271-277), who describe isolation of a pluripotent stem cell from the adult mouse pancreas that can be directed toward an insulin-producing cell. These findings have not been widely

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accepted. First, the result has not proven to be reproducible. Second, the so-called pluripotent cells have never been adequately characterized with respect to phenotype. And third, the cells have certainly not been shown to be pluripotent.

- 5 More recently two other competing technologies have been proposed the use of engineered pancreatic β -cell lines (Efrat S, *Advanced Drug Delivery Reviews*, 1998; 33:45-52), and the use of pluripotent embryonal stem cells (Shamblott MJ et al., *Proc. Natl. Acad. Sci. USA*, 1998; 95:13726-13731). The former option, while attractive, is associated
- 10 with significant problems. Not only must the engineered cell be able to produce insulin, but it must respond in a physiologic manner to the prevailing level of glucose- and the glucose sensing mechanism is far from being understood well enough to engineer it into a cell. Many proposed cell lines are also transformed lines, and therefore have a neoplastic potential.
- 15 With respect to the latter option, having an embryonal stem cell in hand is appealing because of the theoretical possibility of being able to induce differentiation in any direction, including toward the pancreatic β -cell. However, the signals necessary to achieve this milestone remain unknown.

- 20 Islet neogenesis associated protein (INGAP) is a mediator of *in vivo* islet cell neogenesis from pancreatic duct epithelial cells in several species.

- It would be highly desirable to be provided with a method for the *in vivo* induction of re-growth of new insulin-producing cells leading to the formation of mature islets of Langerhans using INGAP peptide (the
- 25 biologically active portion of the INGAP molecule), as a means of revering an established diabetic state. Moreover, if such a diabetic was caused by pre-existing or ongoing autoimmunity, it would also be highly desirable to be provided with a method for the mitigation of such autoimmunity so that the aforementioned newly re-grown cells will not be subjected to ongoing or
- 30 renewed destruction.

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SUMMARY OF THE INVENTION

One aim of the invention is to provide a method to stimulate reversal of a diabetic state in a patient.

- 5 Another aim of the invention is to provide a method to prevent autoimmune destruction of new insulin-producing cells (pancreatic beta-cells) in a patient.

Another aim of the invention is to provide a method to promote survival of the newly regenerated insulin-producing cells (pancreatic beta-cells).

- 10 Another aim of the invention is to provide an *in vivo* method for the induction of islet cell neogenesis and new islet formation and the prevention of autoimmune destruction of the new cells.

- 15 In accordance with the present invention there is provided a method to stimulate reversal of a diabetic state in a patient, which comprises *in vivo* inducing re-growth of new insulin-producing cells (pancreatic beta-cells) by administering a therapeutically effective amount of INGAP peptide to the patient, wherein formation of mature islets of Langerhans is indicative of a stimulated reversal of a diabetic state.

- 20 In accordance with the present invention there is provided a method to prevent autoimmune destruction of new insulin-producing cells (pancreatic beta-cells) in a patient, which comprises administering to the patient a therapeutically effective amount of at least one immunosuppressive agent.

- 25 In accordance with the present invention there is provided a method to promote survival of the newly regenerated insulin-producing cells (pancreatic beta-cells), which comprises administering a pro-survival agent in a therapeutically effective amount to a patient.

- 30 In accordance with the present invention there is provided an *in vivo* method for the induction of islet cell neogenesis and new islet formation and the prevention of autoimmune destruction of the new cells, which comprises the steps of:

- 35 a) administering INGAP peptide to the patient in an amount sufficient to stimulate transformation of putative islet cell stem/progenitor cells in adult pancreas into islet hormone-producing cells (including but not limited to beta-cells) under

normal endogenous homeostatic control mechanisms, whereby cells expand in number and develop a mature glucose-sensing mechanism in a regulated manner;

- 5 b) concurrently administering to the patient at least one immunosuppressive agent in an amount sufficient to protect the islet cells from immune destruction; and
- c) concurrently administering a pro-survival agent to the patient during islet cell neogenesis and new islet formation.

10 The immunosuppressive agent includes, without limitation, sirolimus, tacrolimus, or a combination thereof.

The pro-survival agent includes, without limitation, insulin, IGF-I, IGF-II, and NGF.

15 The term "INGAP peptide" is intended to mean the fragment of native Islet Neogenesis Associated Protein (INGAP) protein which contains the biological activity of the full length molecule, including but not limited to, a biologically active fragment of

Met Leu Pro Met Thr Leu Cys Arg Met Ser Trp Met Leu Leu Ser Cys
1 5 10 15

20 Leu Met Phe Leu Ser Trp Val Glu Gly Glu Glu Ser Gln Lys Lys Leu
 20 25 30

Pro Ser Ser Arg Ile Thr Cys Pro Gln Gly Ser Val Ala Tyr Gly Ser
35 40 45

25 Tyr Cys Tyr Ser Leu Ile Leu Ile Pro Gln Thr Trp Ser Asn Ala Glu
50 55 60

30 Leu Ser Cys Gln Met His Phe Ser Gly His Leu Ala Phe Leu Leu Ser
 65 70 75 80

Thr Gly Glu Ile Thr Phe Val Ser Ser Leu Val Lys Asn Ser Leu Thr
85 90 95

35 Ala Tyr Gln Tyr Ile Trp Ile Gly Leu His Asp Pro Ser His Gly Thr
100 105 110

Leu Pro Asn Gly Ser Gly Trp Lys Trp Ser Ser Ser Asn Val Leu Thr
115 120 125

40 115 120 125
Phe Tyr Asn Trp Glu Arg Asn Pro Ser Ile Ala Ala Asp Arg Gly Tyr
 130 135 140

45 Cys Ala Val Leu Ser Gln Lys Ser Gly Phe Gln Lys Trp Arg Asp Phe
145 150 155 160

Asn Cys Glu Asn Glu Leu Pro Tyr Ile Cys Lys Phe Lys Val

165

170

(SEQ ID NO:1),
a fragment of 15 amino acids of the sequence SEQ ID NO: 1, more
precisely, such an INGAP peptide is of the following amino acid sequence:
5 Gly Leu His Asp Pro Ser His Gly Thr Leu Pro Asn Gly Ser Gly (SEQ ID
NO:2).

The term "islets of Langerhans" is intended to mean islet cells
and associated cells, such as duct cells, of any origin, such as human,
porcine, canine and murine, among others.

10 The term "neogenesis" is intended to mean the regeneration or
de novo growth of cells.

Except as otherwise expressly defined herein, the abbreviations
used herein for designating the amino acids and the protective groups are
based on recommendations of the IUPAC-IUB Commission on Biochemical
15 Nomenclature (*Biochemistry*, 1972, 11:1726-1732).

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the increase in pancreatic insulin content and
the reduction in the prevailing level of blood glucose resulting from the
20 concurrent administration of INGAP peptide and sirolimus/tacrolimus and
insulin in NOD mice.

Fig. 2 illustrates the survival of NOD mice treated with a
combination of INGAP peptide, sirolimus/tacrolimus and insulin versus
animals treated with sirolimus/tacrolimus alone or drug vehicle alone.
25

DETAILED DESCRIPTION OF THE INVENTION

In accordance with the present invention, there is provided a
method for the induction of *in vivo* islet cell neogenesis and new islet
formation from cells derived from islet cell stem/progenitor cells in the adult
30 pancreas, associated with the self-regulated expansion of such cells and
the development of a mature glucose-sensing mechanism, leading to the
reversal of an established diabetic state.

In accordance with one embodiment of the present invention, the
technology is based on the understanding of autoimmune diabetes being a
35 disease state characterized by a loss of an insulin-producing cell mass as
a result of a pre-existing or ongoing autoimmune destruction of such cells,

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incorporating the following components that are necessary and sufficient for the successful reversal of a diabetic state by the induction of islet cell neogenesis and new islet formation:

- 5 1. a stimulus for the induction of islet cell neogenesis and new islet formation from pre-existing pancreatic stem/progenitor cells, provided by, but not limited to INGAP peptide;
2. provision of an immune tolerant environment to prevent ongoing or recurrent destruction of the newly regenerated cells, provided by, but not limited to, a combination of
10 sirolimus/tacrolimus;
3. a pro-survival and anti-apoptosis factor, including but not limited to insulin.

The use of a pro-neogenesis factor is a critical part of the treatment, because without it, there is no stimulus to induce the
15 transformation of putative stem/progenitor cells to new hormone-producing islet cells. Alternatively, there may be such an endogenous stimulus but it may be ineffectual in terms of overcoming a much more effective ongoing cell destruction process. Hence it is the balance of neogenesis versus destruction that may be important.

20 Autoimmune diabetes, by definition, occurs through the autoimmune destruction of insulin-producing pancreatic beta-cells. In order to mitigate the ongoing or renewed destruction of such cells after the induction of islet cell neogenesis, the local immune environment must be altered to remove or diminish this autoimmune insult. Thus
25 immunosuppressive agents, that include, but are not limited to a combination of sirolimus/tacrolimus, are required.

Newly created beta-cells are known to be quite sensitive pro-death signals including, but not limited to high levels of circulating glucose. Thus pro-survival factors and in particular factors that can mitigate high
30 levels of circulating glucose including, but not limited to insulin, are important to support and sustain cell survival.

Evidence for the induction of islet cell neogenesis and new islet formation leading to the reversal of diabetes includes: (1) an increase in the expression of the transcription factor Pdx-1 in putative islet cell progenitor
35 cells; (2) and increase in pancreatic insulin content; (3) an increase in beta-

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cell mass; (5) a decrease in the prevailing level of blood glucose; (6) an increase in survival.

While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modifications and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth, and as follows in the scope of the appended claims.

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WHAT IS CLAIMED IS:

1. A method to stimulate reversal of a diabetic state in a patient, which comprises *in vivo* inducing re-growth of new insulin-producing cells (pancreatic beta-cells) by administering a therapeutically effective amount of INGAP peptide to said patient, wherein formation of mature islets of Langerhans is indicative of a stimulated reversal of a diabetic state.
2. A method to prevent autoimmune destruction of new insulin-producing cells (pancreatic beta-cells) in a patient, which comprises administering to said patient a therapeutically effective amount of at least one immunosuppressive agent.
3. The method of claim 2, wherein said immunosuppressive agent is selected from the group consisting of sirolimus, tacrolimus, and a combination thereof.
4. A method to promote survival of the newly regenerated insulin-producing cells (pancreatic beta-cells), which comprises administering a pro-survival agent in a therapeutically effective amount to a patient.
5. The method of claim 4, wherein said pro-survival agent is selected from the group consisting of insulin, IGF-I, IGF-II, and NGF.
6. An *in vivo* method for the induction of islet cell neogenesis and new islet formation and the prevention of autoimmune destruction of said new cells, which comprises the steps of:
 - d) administering INGAP peptide to said patient in an amount sufficient to stimulate transformation of putative islet cell stem/progenitor cells in adult pancreas into islet hormone-producing cells (including but not limited to beta-cells) under normal endogenous homeostatic control mechanisms, whereby cells expand in number and develop a mature glucose-sensing mechanism in a regulated manner;

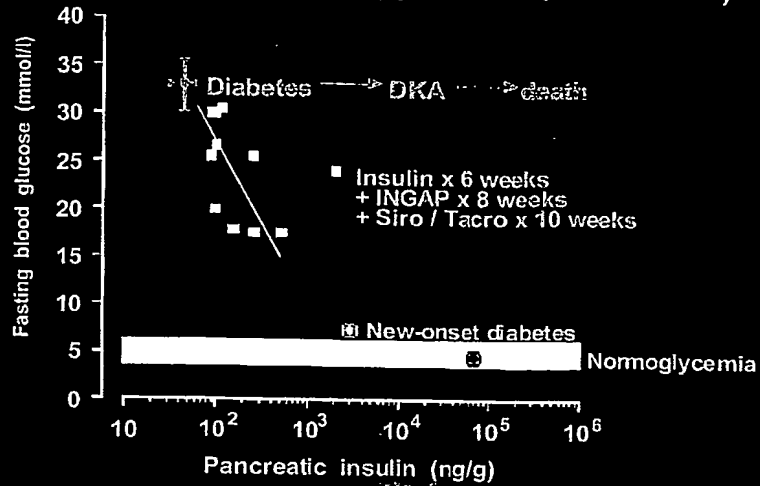
-13-

- e) concurrently administering to said patient at least one immunosuppressive agent in an amount sufficient to protect said islet cells from immune destruction; and
 - f) concurrently administering a pro-survival agent to said patient during islet cell neogenesis and new islet formation.
7. The method of claim 6, wherein said immunosuppressive agent is selected from the group consisting of sirolimus, tacrolimus, and a combination thereof.
8. The method of claim 6; wherein said pro-survival agent is selected from the group consisting of insulin, IGF-I, IGF-II, and NGF.

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ABSTRACT OF THE INVENTION

The present invention relates to a method to stimulate reversal of a diabetic state in a patient; a method to prevent autoimmune destruction of new insulin-producing cells (pancreatic beta-cells) in a patient; a method to promote survival of the newly regenerated insulin-producing cells (pancreatic beta-cells); and an in vivo method for the induction of islet cell neogenesis and new islet formation and the prevention of autoimmune destruction of said new cells.



Islet Neogenesis-Associated Protein (INGAP) Plus
Immunosuppression (Sirolimus + Tacrolimus) Promotes
Survival of Diabetic NOD Mice Withdrawn from Insulin Therapy

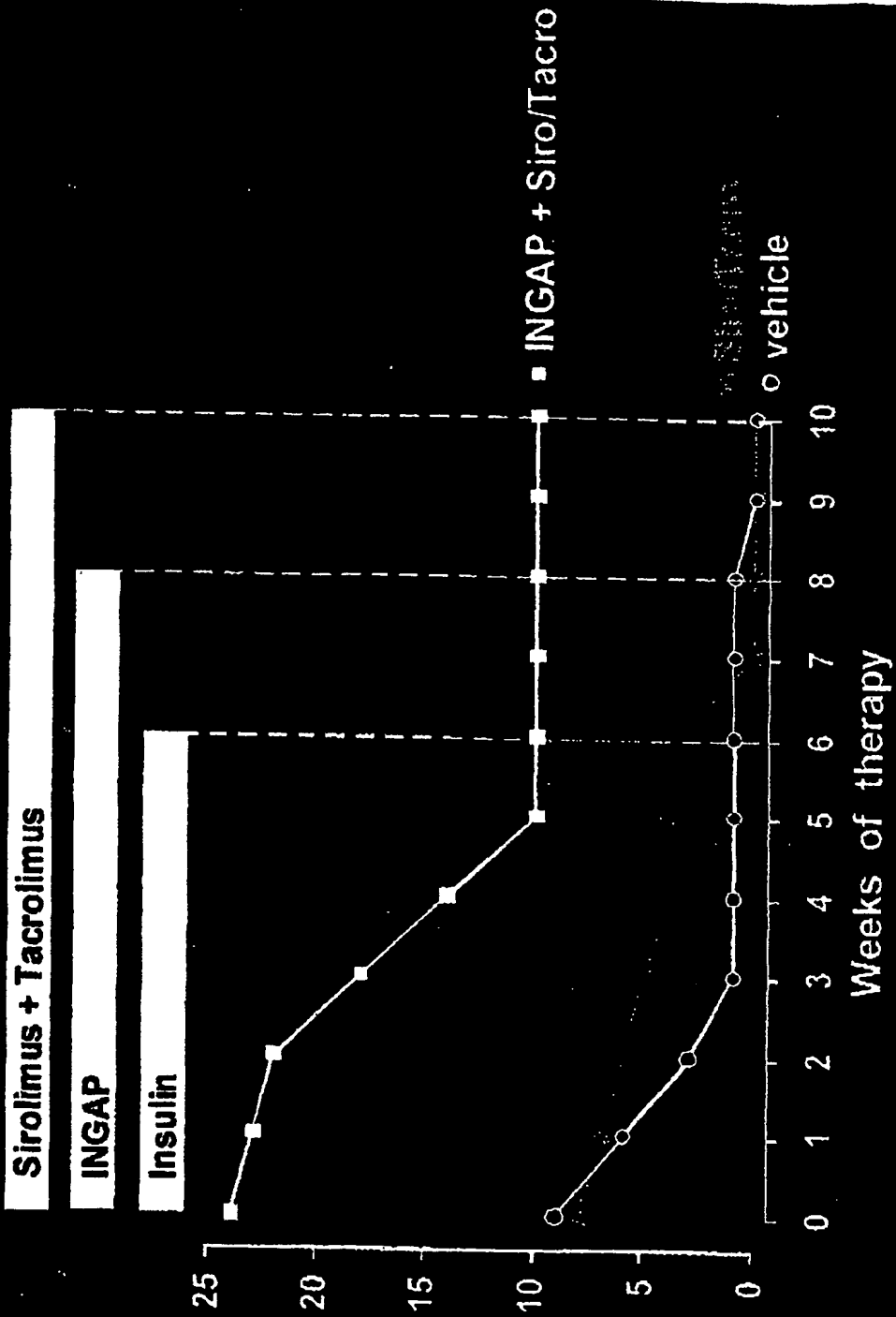


Fig. 2

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